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BENEFITS OF FACTS CONTROLLERS OVER AC TRANSMISSION SYSTEMS

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ABSTRACT

This paper is concerned with "Fundamentals of FACTS".The primary focus of this paper is to summarise the issues and benefits regarding the application of FACTS controllers to AC power systems. The complete process aimed at system studies and analysis relatedtothe installation of FACTS projects and the simultaneous need in accordance with FACTS controller models has been discussed. Also, an introduction towards the basic circuits of several FACTS controllers has beengiven with a prime focus on performance characteristics of their system.

KEYWORDS: Facts, Power System Stability, Power Electronic Equipment, Power System Control

INTRODUCTION

Electricity is regarded as a highly engineered product;butit is gradually being considered and handled as a commodity. Accordingly, transmission systems are gettingstretched closer to the limits of their stability as well as thermal limits whereas the main focus on the quality of power delivered has increased significantly.

Nowadays, advanced technologies are highly-needed for the reliable as well as secure operation of power systems. For achieving both operational reliability and financial profitability, *existing* transmission systems infrastructure's utilization is vital in a more effective and measured way. Enhanced utilization of the current power system is deliveredby the help of advanced control technologies. Flexible AC Transmission Systems (FACTS) or Power electronics based equipment, have provided proven technical solutions to meet the new operating challenges which are being presented nowadays. FACTS technologies let us to go for improved operation of transmission system involving minimal infrastructure investment, along with less environmental impact, and low implementation time when compared to the new transmission lines construction.

The budding benefits of FACTS equipment are now getting wide recognition by leading power systems engineering and T&D communities. In accordance With FACTS equipment, VSC(voltage sourced converter) technology employing self-commutated thyristors/transistors such as GTOs, GCTs, IGCTs, and IGBTs has been successful in applying a number of world-wide installations for Static Synchronous Compensators (STATCOM) [1-5], Unified Power Flow Controllers (UPFC) [6, 7], Convertible Series Compensators (CSC) [8], back to-back dc ties (VSC-BTB) [9, 10] and VSC transmission [11]. Along with these referenced and other applications, there are numerous recently accomplished STATCOMs in the U.S., in the states of California [12], Vermont [13, 14], and Texas [no references available]. Furthermore, there are newly planned STATCOMs in Connecticut [15] and Texas, in addition toa small STATCOM (D-VAR) planned for BC Hydro [16] and some other locations. An additional power electronic equipment installation includes Distributed Superconducting Magnetic Energy Storage units (D-SMES) [17]. These above-mentioned transmission system installations are along with the previous generation of power electronics systems utilizing

line-commutated thyristor technology for Static Var Compensators (SVC) [18] and Thyristor Controlled Series Compensators (TCSC) [19-22].

POWER SYSTEMS'S CONTROL

- Generation, Transmission, Distribution

When we discussthe utilization, movement and creation of electrical power, we can separate it into three areas, which usuallyhave determined the organization ofelectric utility companies. These are demonstrated inFigure 1 and are:

- Generation
- Transmission
- Distribution

Figure 1: Scheme Depicting Utilization, Movement, Creation and of Electrical Power

Although there is a dominance of power electronic based equipment in each of these three areas, e.g. with static excitation systems for generators and Custom Power equipment in distribution systems [23], this paper is aimed on transmission, that is, movement of the power from source (where it is generated) to sink (where it is utilized).

Constraints in Power System

The constraints of the transmission system can appear inmany forms and they may include transfer of power between areas (mentioned here as transmission blockages) or within a single area or region (mentioned here as a regional restraint) and may consist of one or more of the following characteristics:

- Damping Limits of Oscillation in Power System.
- Stability Limit of Voltage.
- Current Limit of Short-Circuit
- Limit of Transient Stability
- Limit of Steady-State Power Transfer
- Limitof Inadvertent Loop Flow
- Thermal Limit
- Limitof Dynamic Voltage
- Others

Each transmission blockage or regional restraint maycomprise of any number of these system-level problems. The fundamental to overcome these roadblocks in a most cost-effective and coordinated manner is by applying thoroughengineering analysis of systems, as described in this paper's later segments.

- **Power Systems' Controllability**

To exemplify that there are certain variables the power system only has that can be impacted by control, take into account theelementaryand renowned power-angle curve, presentedin Figure 2. Even though this is a steady-state curve and the FACTS implementation is predominantly for dynamic issues, this designproves the point that there are mainlythree main variables whose direct control in the power system might have an impact on performance. They are:

- Voltage
- Angle
- Impedance

Also, it can benoted that direct control of power is a fourth variable which commands control in power systems. By establishing "what" variables we can exercise control in a power system, the next question popping up is "how" these variables can be controlled. This is answered in two parts: namely FACTS controllers and conventional equipment.

FACTS Controllers' Examples

- Unified Power Flow Controller (UPFC)
- Convertible Series Compensator (CSC)
- Inter-phase Power Flow Controller (IPFC)
- Static Synchronous Compensator (STATCOM)

  Controlling voltage
- Static Var Compensator (SVC)

  Controlling voltage
- Static Synchronous Series Controller (SSSC)

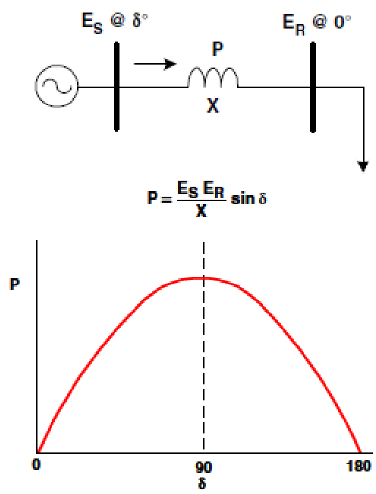

Figure 2: Illustration of Controllability of Power Systems

Conventional Equipment's Examples

- Series Capacitor

  -used for Impedance Control

- Reactor and Switched Shunt-Capacitor

  - used for controlling voltage

- Transformer LTC

  - used for voltage control

- Phase Shifting Transformer

  - used for controlling angle

- Synchronous Condenser

  -used for voltage control

- Special Stability Controls

  -Typically they focus on controlling voltage but direct control of power can often be included

- Others (On inclusion of Thermal Limits)

  -Can comprise of raising conductors, adding new lines, dynamic line monitoring, re-conductoringetc.

  -Each of the aforementioned (and similar) impedance, controller impact voltage, and/or angle (and power)

- Thyristor Controlled Series Compensator (TCSC)- Impedance control
- Thyristor Controlled Phase Shifting Transformer(TCPST) –Angle control
- Super Conducting Magnetic Energy Storage (SMES) –used for controlling voltage and power

The fundamental to overcome these roadblocks in a most cost-effective and coordinated manner is by applying thorough engineering analysis of systems. This may includecomparison between the system benefits available by conventional equipment and fromthe FACTS controllers. An important distinction can be made when differences in these two solution options are considered. Figure 3 illustrates a few cycles of voltage at the frequency of power system. It also displays that for conventional equipment solutions the speed of mechanical switches (or primarily circuit breakers) can be as fast as a couple of cycles of 60 (or 50) Hz. This on and off switching speed on its own may be fast enough to overcomeseveral power system constraints. Even though there is a massive improvement in switching time when we have moved frommechanical to power electronic based solutions (Figure 3 illustrating that the speed of power electronics switches is a fraction of a cycle), the main profitoffered by FACTS controller solutions is the "smooth control" and "cycling/repeatability" which are accompanied bythe power electronic based switching. To put it differently, a conventional (mechanically switched based) solution is one which impacts the power system by "on or off" in the time frame needed for power system stability, whereas solution based on the power electronic can be a smooth, continuous, and/or repeatable option for power system control. Hence by the application of power electronic based solutions to

improve constraints of power system, not only ‘speed’ but “smooth control” and “cycling” arealso gained.

- **Benefits of Having Power Systems’ Control**

Once we have identified power system constraints as well as through system studies viable solutions options, we need to determine the benefits of the added power system control. The list of such benefits is as follows:

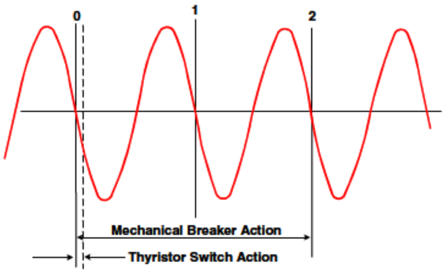

Figure 3: Illustration of the Speed of Power System Control

- More Effective Use of

  Transmission Corridors and Increased Loading
- Added Power Flow Control
- Improved Power System Stability
- Increased System Security
- Increased System Reliability
- Addition of Flexibility in Generation of New Siting
- Deferral or Elimination of the Need for NewTransmission Lines.

The advantages mentioned in this list are significantwhen we want to achieve the overall planning and operation of power systems. However, for simply mitigating the costs involved in implementing added power systemcontrol as well as for comparing conventional solutions to FACTS controllers, there is often the need of more specific metrics of the benefits to the power system. These benefits can usually be clubbed back to an area or region for a specific season and time of year at a defined dispatch (usually provided by an ISO or equivalent) ensuring following criteria is fulfilled, for example:

- Criteriafor Stability of Voltage

  -e.g., minimum margin having P-V voltage or power criteria.

  -e.g. minimum margins having Q-V reactive power criteria
- Criteria for Dynamic Voltage

  -e.g. Avoiding collapse of voltage

  -e.g. criteria for Minimum transient voltage dip/sag

  (magnitude and duration)

- Criteria for Transient Stability
- Damping of Power System Oscillation

  -e.g. Minimum damping ratio

- Others

We can usually measure each of afore mention editems in terms of a physical quantity such as power transfer involving acritical transmission interface, output of a power plant, and/or load level of an area or region. This in turn allows for a direct quantification ofthe aids of adding control of power systemand in turn provides us with a means to compare such benefits by considering the various solution options, whether they are conventional or based on FACTS.

PHASES INVOLVED IN STUDY OF POWERSYSTEM FOR INSTALLATION OF FACTS PROJECTS

Figure 4 displays the view of author of the overall system studies process associated with installation of FACTS projects. The subsequent subsections will provide the basic objectives and certain details for each study phase in a bullet list format.

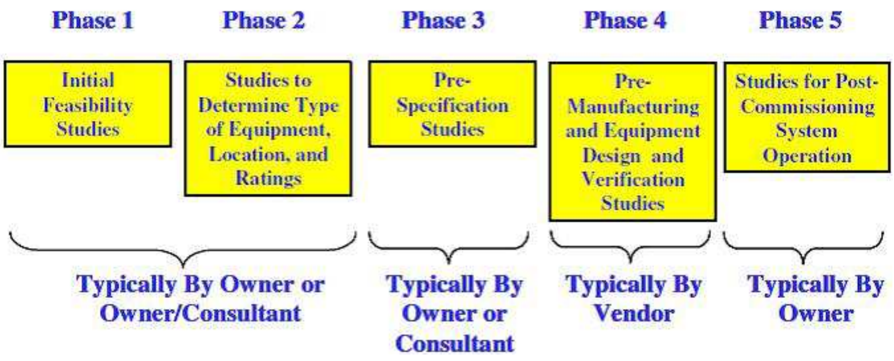

Figure 4: Phases -Power System Studies for FACTS Installation Projects

A. Phase 1: To Determine System Constraints and Needs for Reinforcement through Initial Feasibility Studies

The Main Objectives for Phase 1 Type Studies are:

- Identification of Characteristics of Power System.
- Identifying Problems related toSystem Performance:-

  -Transient instability

  -Oscillatory instability

  -Dynamic voltage instability

  -Voltage collapse

  -Thermal ratings (power flow)

- Identify the Transmission Constraints that require independent examination andones that require aCoordinated Analysis

- Identification of the Reinforcement Needs e.g.Shunt vs. Series and Slow vs. Fast.

Phase 1 type studies for the foremost study tools and FACTS model requirements are:

- Load Flow Programs
- Stability Programs
- Modelling of Positive Sequence Only
- Power System's full Scale Model.
- Study can be done usingSimple Device Models

Phase 1

Key deliverables of Phase 1 type studies:

- A Vital Understanding of the Features of the Power System -Key areas and interfaces affected
- System Performance Problems' Identification

  -Dynamic voltage instability

  -Voltage collapse

  -Transient instability

  -Oscillatory instability

  -Thermal ratings (power flow)

- Identification of constraints that require independent examination as well as ones that require Coordination.
- To identify the "Type" of System Reinforcements which are most effective e.g. Shunt vs. Series and Slow vs. Fast.

B. Phase 2: Determining Type of Equipment, Location, and Ratings by Studies

Phase 2 Typestudies' Key Objectives:

- Identify Solution Options which are both Conventional and FACTS and Combinations Thereof
- Solution Options based on PerformanceEvaluation.
- Other Issues' consideration

  -Location

  -Solution options'Economics

  -Losses

  -Interaction done with other devices

- Evaluation of economics of Each Option's Costs against Value of Power System Benefits.

Phase 2 type studies' main study tools and FACTS model requirements:

- Programs of Stability
- Programs forLoad Flow
- Power System with Full Scale Model
- Modelling of Positive Sequences
- Models of Device

  -Models Load flow

  -Models of Stability

  -Models of Control.

Phase 2 type studies are similar to Phase 1 type studies in basic modelling and study requirements;the difference is the added requirement of more detailed device models. Analysis of Electromagnetic transients is typically not vital at this stage. In Phase 2 it is required to identify solution possibilities for system voltage control if the analysis of Phase 1 shows that the system is having a problem with voltage. These include:

- In case of Voltage Collapse (slow), Consider:

  -Shunt capacitor banks

  -Series capacitors

  -Static shunt compensators (e.g., STATCOM, SVC)

  -Static series compensators (e.g., SSSC)

  -Combination

- In case of Dynamic (fast) Voltage Variability, Consider-

  -Shunt capacitor banks

  -Static shunt compensators (e.g., STATCOM, SVC)

  -Combination

During Phase 1 analysis if the system is having a problem with the stability of rotor angle, then in Phase 2 solution options are needed to be identified or this type of issue.Thesemay include:

- For Oscillatory Instability, Consider:

  -Power system stabilizers (PSS)

  -Adding Damping controls to static shunt or series

  Compensators

Deliverables Identified during Phase 2 Type Studies are:

- Identifying Viable Solution Options

  -Consideration of both conventional and FACTS andcombinations thereof-

  Ranking of all viable solutions in terms of system benefits

- For Transient Instability, Consider:

  -Static shunt compensators (e.g., STATCOM, SVC)

  -Series capacitors

  -Static series compensators (e.g., SSSC)

  -Combination

- Identifying Suitable Location to Install the Solution Options -Choice may be obvious or depend on the solution to be

Implemented -Site work and permission etc. might be a key factor

- Evaluation of Economics of Each Option's Overall Costs vs. Value of Power System Benefits

  -Ranking of all viable solutions in terms of whole economics

C. Phase 3: Equipment Requirements Defined by Pre- Specification Studies

The Key Points during Phase 3 Type Studies are:

- Writing a Technical Specification and RFP which can be submitted to Potential Bidders

A technical specification consists of a variety of technical items which are to be published must be determined apriority by system studies. These may or may not includethe following:

- Rating, Location and Device Type (From Phase 2 Studies)
- Descriptions of System

  Operating voltage (Minimum and maximum) for steady stateand transient conditions (MCOV, BSL, BIL, etc.)

  -Corresponding X/R ratios for Maximum, minimum, emergency, and ultimate system strength

  -Frequency excursions (Minimum and maximum)

  -Maximum unbalance for negative and zero sequence.

- Requirements for Dynamic Performance of Systems.

  -Developing strategies for system performance n transient and steady-state

- Harmonic Limits and System Characteristics

  -Maximum total harmonic distortion (D)

  -Maximum individual harmonic distortion (Dn)

-Impedance helps in wrappings for normal and contingency conditions

-Telephone interference limit (TIF)

- Interference Issues and Limits of High-frequency help in:

  -Determining maximum tolerable limits on radio interference (RI) noise and power line carrier (PLC) noise.

Preparation of Other Items

- Impedance map and System one-line diagram
- Data sets for Load flow and Stability
- Requirements for performance of equipment
- Availability/Reliability criteria
- Acceptable Failure Rate of components
- Control objectives (steady state and transient)
- Voltage imbalance
- Response times
- Loss evaluation criteria, associatedcost/penalty as well as formula.

Deliverables of Phase 3 Type Studies are:

- RFP and Technical Specification to be submitted to PotentialBidders

D. Phase 4: Pre-Manufacturing andVerification Studiesand Equipment Design

Deliverables during Phase 4 Type Studies are:

- Verifying to the Owner that the Device which is described by the Specification ismeeting all the requirement ofsystem and Equipment performance.
- Completing the Detailed Design for Equipment, Manufacturing and Procurement for:
- Control and Protection (Hardware and Software)
- Inverters
- Insulation Coordination
- Filters
- High-voltage and low-voltage equipment Etc.

E. Phase 5: System Operation Post-Commissioning Studies

The Key Deliverables for Phase 5 Type Studies are

- Verifying whether the Network Load Flow Conditions are falling within limits of Benchmark set for them.
- Confirming the Installation of Equipment to Enhance Network Dynamic and Steady-state Performance.

- Setting up Instrumentation and Obtaining Measurements during Staged Fault Tests and Actual Faults/Dynamic Events
- Ensuring that Adverse Interactions with Other System Equipment are not there.
- Equipment's Reliability/Availability to be Measured
- Establishing Algorithm of Operational Losses.

CONCLUSIONS

Summary of "FACTS Fundamentals" is provided in this paper.This paper also emphases on a summary of the issues as well as benefits which are obtainedwhen FACTS controllers applied to AC power systems. Discussion on the overall process for analysis and system studies associated with FACTS installation projects and the need for FACTS controller models was also done. Finally, basic circuitshave been introduced several FACTS controllers with a focus on their system performance characteristics was provided.

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